A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

LA-UR-89-1918

LA-UR--89-1918

DE89 014025

TITLE: Precision Electroweak Physics with Neutrinos at Los Alamos

AUTHOR(S): Gary H. Sanders

SUBMITTED TO: The Proceedings of the XXIVth Rencontres De Moriond, Electroweak Interactions and Unified Theories, Les Arcs, France, March 5-12, 1989

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO 836 R4
ST NO 2629 5/81

PRECISION ELECTROWEAK PHYSICS WITH NEUTRINOS AT LOS ALAMOS

Gary H. Sanders
Los Alamos National Laboratory

ABSTRACT

We review the status of current efforts at Los Alamos to measure the mass of $\overline{\nu}_e$ with tritium beta decay and to search for oscillation of $\overline{\nu}_\mu$ to $\overline{\nu}_e$. A new proposal to carry out a precision measurement of the electroweak mixing angle, θ_W, using neutrino-electron scattering measured in a 7000-ton water Čerenkov detector, the Large Čerenkov Detector (LCD), is described.

In this talk, I would like to bring you up to date on two experiments at Los Alamos that address related aspects of neutrino physics and tell you a little about our proposed future efforts with neutrinos. The new initiative to explore neutrino-electron scattering with a large water Čerenkov detector exploits the unique beam characteristics available at our LAMPF accelerator to carry out a precision test of the standard electroweak theory. The test will be sensitive to the radiative corrections which modify neutrino-electron scattering at the one-loop level.

Tritium Beta Decay and the Mass of $\bar{\nu}_e$

Since the report by Lubimov et al.[1] in 1980, of a nonzero mass for $\bar{\nu}_e$, based upon a precision measurement of the end-point energy of the beta-decay spectrum from tritium, many groups have repeated the experiment, employing a variety of techniques. The current status of the results is that Lubimov reports[2] a best fit value of $m_{\bar{\nu}_e} = 26^{+6}_{-5}$ eV and a preferred model-independent range of $17 < m_{\bar{\nu}_e} < 40$ eV, and the Zurich group[3] reports the most stringent published limit of $m_{\bar{\nu}_e} < 18$ eV. These experiments, and several others, provide some assurance that no particular systematic effect is likely to lead to an enduring erroneous result, since the experimental approaches are quite varied. The Los Alamos effort, based upon the novel use of a gaseous source of tritium, is designed to be free of the effects associated with solid sources. To date, their best result has been to set a limit $m_{\bar{\nu}_e} < 27$ eV.[4]

The Los Alamos experiment uses an intense molecular tritium source with an improved Tretyakov-type[5] spectrometer. An additional field is used to accelerate electrons into the spectrometer in order to suppress backgrounds from tritium decays within the spectrometer. A Kr source is used to measure the resolution function. The apparatus has been described in detail elsewhere.[6]

Since their 1986 result,[4] the group has improved the experiment in a number of ways. They replaced the single proportional counter with a silicon microstrip detector which increased the acceptance. They improved the solenoid field with a gradient, eliminating trapping, and baffled the spectrometer fields to control the acceptance. They reduced atmospheric buildup with a getter pump and carried out a careful study of the Kr lineshape tails with synchrotron radiation in order to improve their understanding of the resolution function. This improvement program[7] was designed to bring the sensitivity of the experiment to 10 eV, limited by statistical errors and backgrounds, and not by systematic uncertainties. Table I summarizes the rate improvements resulting from these, and other improvements. The net effect is a factor of 23 in improved data collection rate.

Table I. Rate Improvements

Action Taken	Improvement in Rate
Si strip focal detector	8
Apparatus realignment	1.3
Solenoid gradient	0.75
Tritium flow getter pump	2
Optimization of data collection	3
Baffling spectrometer acceptance	0.5
	23

With these improvements completed, data were collected during 1988 and the analysis is in progress. With the new focal detector, the physics analysis is complicated by the need to perfect the pad readout analysis, and this is in progress.

In addition, tails on the Kr internal-conversion electron spectrum lineshape have required an additional study which is nearly complete. This lineshape is used to validate the spectrometer resolution function. Any error in the knowledge of this function obscures the beta-decay endpoint measurement and, therefore, the mass of the neutrino, which is unfolded in the analysis. Figure 1 shows the spectrum from the internal conversion, and a measured spectrum from photoionization of Kr carried out by the collaboration at SSRL. The agreement shown validates the hypothesis that the low-energy tail is due to the effects of the Kr electron interacting with outer electrons in the Kr atom. This model is further validated by the comparison shown in Fig. 2 in which the "shakeoff" model is compared to the SSRL data. The agreement is good.

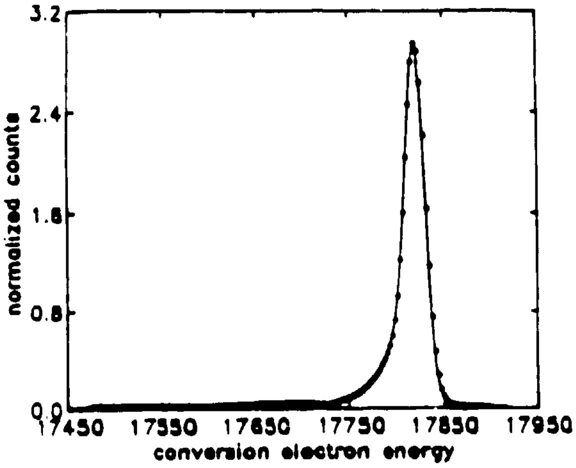

Fig. 1. Comparison between electron spectra from 1s photoionization of Kr (line) and internal conversion (points).

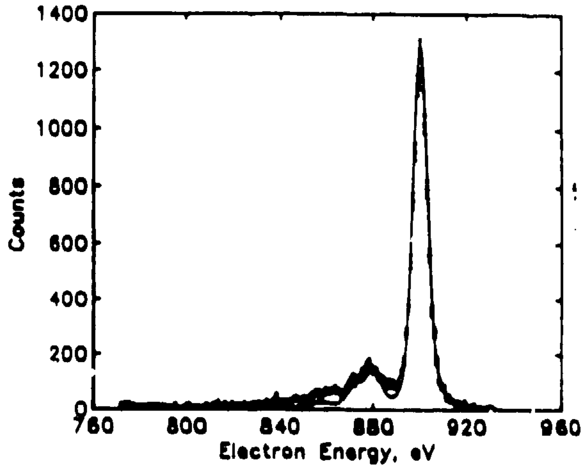

Fig. 2. Comparison between calculated electron spectrum for 1s photoionization of Kr (line) and data (points).

Results from the new experiment should be forthcoming, as the new improvements are incorporated into the analysis. The goal of 10-eV sensitivity seems feasible.

Search for Neutrino Oscillations (Appearance of $\bar{\nu}_e$)

The 800-MeV, 1-ma average proton beam from the linear accelerator at the Los Alamos Meson Physics Facility (LAMPF) is currently being used to search for the appearance of $\bar{\nu}_e$ in a large detector that is exposed only to incoming ν_e, ν_μ, and $\bar{\nu}_\mu$. These neutrino varieties come from π^+ decay in the beam stop, whereas the π^- component is captured, leaving at most a contamination of $\bar{\nu}_e$ below the 10^{-3} level. The proton beam has a low duty factor (6 10%) which aids in the suppression of cosmic ray induced backgrounds.

The experiment (LAMPF experiment 645) is an Argonne Caltech LBL LAMPF Louisiana State Ohio State collaboration. The detector is shown in Fig. 3. It consists of an active cosmic ray shield made up of liquid scintillators, a passive shield made of lead, a 2000-gm/cm^2 overburden to reduce incoming neutral particles, and a 20 ton active detector made up of liquid scintillators and drift tubes. The central detector is sensitive to $\bar{\nu}_e$ by observing the recoil positron from inverse beta decay [$p(\overline{\nu}_e, e^+)n$], and has a limited neutron detection capability. The detector views the beam stop from a distance of 26 m. In the usual two-component description of oscillations, this experiment has an $L/E_\nu = 0.65$. Its sensitivity is similar to that of other experiments at higher energy.

The first significant data were collected by this group in 1987. In an exposure to 5100 coulombs at the LAMPF beam stop, the group set limits on the oscillation shown in Fig. 4. These results have been published,[9] and are not consistent with early, preliminary reports of oscillations from BNL and CERN experiments. The group has now collected additional data from a 4200-coulomb exposure and expects to set limits more stringent than those shown by approximately a factor of two. The experiment, in the absence of a positive effect, will then be completed. However, a group of collaborators[10] is forming to replace the inner detector with a mineral oil detector. This experiment may have sensitivity improved by an order of magnitude.

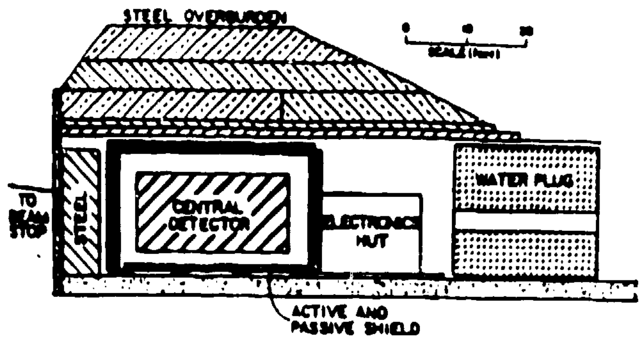

Fig. 3. The neutrino detector and cosmic-ray shield used in the LAMPF search for the appearance of $\overline{\nu}_e$.

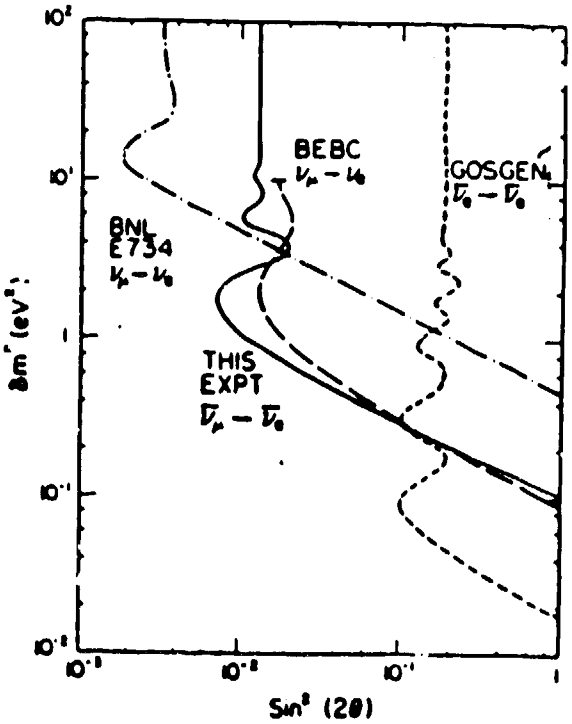

Fig. 4. The 90%-confidence-level contour for the region of δm^2 and $\sin^2(2\theta)$ excluded by this experiment. Other recently published limits are shown for comparison.

The Large Čerenkov Detector

During the next 5–10 years, the new high-energy electron-positron colliders will measure the mass of the W and Z bosons to very high precision. This measurement will provide an accurate determination of the electroweak mixing angle θ_W of the electroweak theory. However, only when combined with a sufficiently accurate measure of this angle at low energies can the predictions of the electroweak theory be verified at the level of one-loop radiative corrections.[11] The high-energy measurements address only the first-order "tree level" contributions. Deviations from the Standard Model predictions are a signature of new physics.

A low-energy measurement of the electroweak parameter based upon neutrino electron scattering is particularly clean because of the simplicity of the neutrino Z vertex. The value obtained from neutrino-electron scattering at LAMPF energies can differ from the collider value by as much as 7%, due to the energy-dependent radiative corrections. Furthermore, only the beam properties at LAMPF make this measurement possible at the required precision. The precision proposed for the LAMPF Large Čerenkov Detector is better than 1%.

In the Standard Model, it can be shown that the ratio of scattering cross sections,

$$R = \frac{\sigma(\nu_\mu e)}{\sigma(\nu_e e) + \sigma(\overline{\nu}_\mu e)} \quad ,$$

can be written in terms of the mixing angle as, if $s = \sin^2\theta_W$,

$$R = \frac{3}{4}\,\frac{1 - 4s^2 + \frac{16}{3}s^4}{1 + 2s^2 + 8s^4} \quad .$$

By measuring the ratio R to better than 2% precision, the mixing angle is determined to better than 1% precision. It is this measurement of neutrino electron scattering that is proposed for the new Large Čerenkov Detector at LAMPF, by a Los Alamos-Irvine-UCLA-Colorado-CEBAF-Moscow-New Mexico-Pennsylvania-Temple-William and Mary-Riverside collaboration.

The conventional way to measure this ratio would be to employ two different neutrino beams, one rich in ν_μ and a second beam rich in ν_e and $\overline{\nu}_\mu$, in sequence. The first species is produced in pion decay, the second in muon decay. Changing over from a pion rich to muon rich beam might be done in alternate months of running, for example. Carrying out a precision experiment in this manner would be very difficult. The time structure of the LAMPF beam, as prepared by the new Proton Storage Ring, is a 270-ns-long pulse repeated 12 times per second. Since pion decay and muon decay are characterized by such widely differing lifetimes, neutrinos observed in the first several hundred ns are those in the numerator of the expression defining R. The muon decays occur over several microseconds, yielding the cross sections in the denominator. Thus, every PSR pulse yields a neatly time-separated neutrino beam. Figure 5 shows this neutrino yield as a function of time from each PSR pulse. By recording the time of each recoiling electron from a neutrino scatter, the ratio which determines R can be unfolded by fitting the time-dependence of the data set.

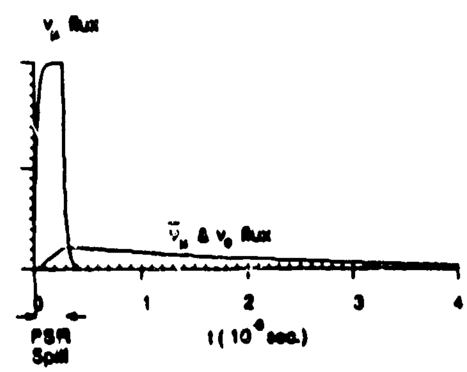

Fig. 5. Time distribution of neutrinos from each pulse into the Large Čerenkov Detector beam stop.

The Large Čerenkov Detector system is shown in an isometric drawing in Fig. 6. The PSR beam is transported in a 100-m-long beam line that features very low losses and a superconducting dipole that bends the beam 90° down into the LCD beam stop. The target is surrounded by a massive 15-m diameter iron shield designed to reduce all backgrounds from neutrons to an acceptable level. The neutrinos exit the shield into a cylindrical water tank 32.2 m in diameter and filled with water to a depth of 15.6 m. The outer veto region of the water is typically 1.5 m thick, and the fiducial volume contains approximately 7000 tons of water. Viewed by about 10000 photomultipliers, each approximately 25-cm diameter, the photocathodes cover nearly 20% of the tank surface. This fine-grained imaging counter should achieve a 10 MeV threshold with 27 photoelectrons in a minimum of 20 phototubes as a primary trigger.

In a 625-day run, at 100 μA average beam current, there will be 12 events per day from $\nu_\mu e$ and 101 events per day from $\overline{\nu}_\mu e$ and $\nu_e e$, for a total of 7500 and 63,400 events, respectively. The

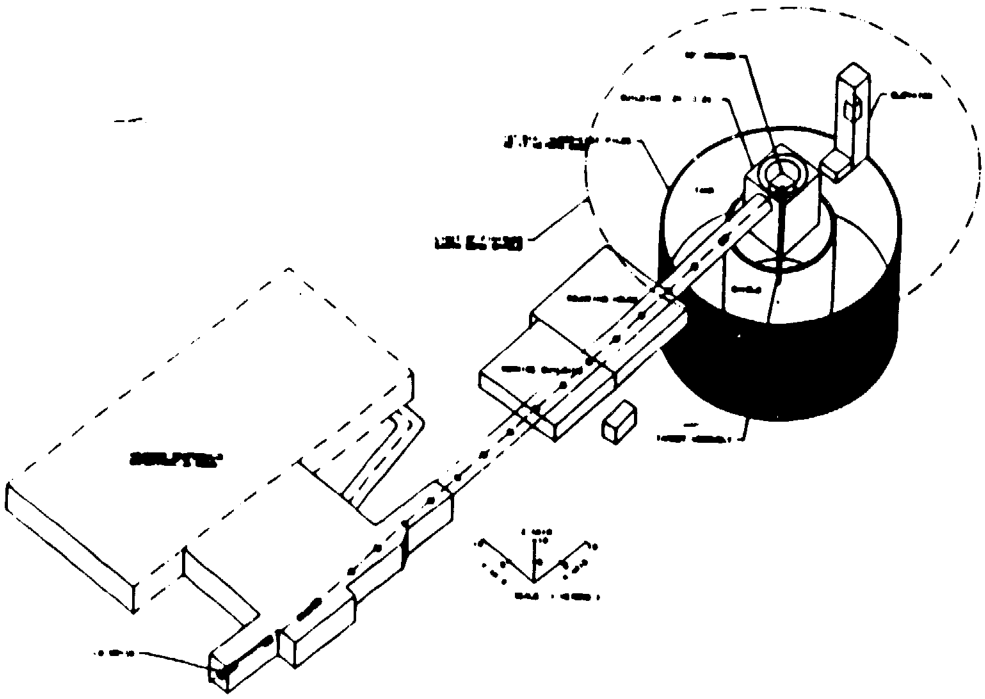

Fig. 6. Isometric view of the Large Čerenkov Detector.

total statistical error on R is about 1.6% from counting statistics, PSR pulse shape variations, cosmic ray and neutron induced background subtractions, and ν_e-oxygen scattering. Systematic errors total 1.86% in R. The combined total error in $\sin^2\theta_W$ is then 0.89%. Systematic errors come from decay in flight, cosmic rays, photons and $\pi^{\pm}$ from neutron interactions, threshold energy uncertainties and nonuniform efficiency.

The Large Čerenkov Detector will be capable of addressing several other fundamental topics at the same time the Standard Model study is carried out. These include several types of neutrino oscillation searches, searches for neutrino structure such as a charge radius or magnetic moment, observation of neutrino bursts from supernovae, searches for upward-going muons, lepton-number nonconservation, and heavy neutrinos or axions.

Neutrino oscillations can be detected in departures of the ratio R from the Standard Model predictions, observation of radial oscillations in the cylindrical detector volume, and observation of a contribution to the ν_e-oxygen signal with a monoenergetic signature. Since the $\nu_e e$ cross section is seven times larger than the other $\nu_\ell e$ cross sections, LCD can search for the processes $\nu_e \leftrightarrow \nu_\mu$ [12,13] and $\nu_e \leftrightarrow \nu_\tau$ by measuring an increase in R. Disappearance experiments [$\nu_\mu \rightarrow \overline{\nu}_\mu$ (sterile), $\nu_e \rightarrow \overline{\nu}_e$ (sterile)] also show up as changes in R.

By unfolding the radial dependence of the events, oscillations that occur with a wavelength close to the tank radius are detectable, particularly in the prompt signal from the monoenergetic ν_μ, or in the ν_e-oxygen event radial distributions. Since the LCD beam stop produces monoenergetic ν_μ, the process $\nu_\mu \rightarrow \nu_e$ will result in prompt ν_e-oxygen events which are monoenergetic.

The best sensitivity will likely be achieved in the search for the process $\overline{\nu}_\mu \leftrightarrow \overline{\nu}_e$, the same process sought in the current LAMPF experiment. In the LCD case, the signal is the inverse beta decay, which is observable above the leading background from ν_e-oxygen events. In the usual two-component oscillation description, LCD should achieve limits on the quantity $\sin^2 2\alpha$ of about 2×10^{-4}. Detailed sensitivities for these and other oscillation processes are presented in the full proposal.[14]

If the electron or muon neutrino has a sufficiently large magnetic moment or charge radius, then LCD will observe an anomalous value of R and an anomalous y distribution ($y = E_e/E_\nu$). A nonzero magnetic moment (or electric moment) increases the neutrino-electron cross section and makes the y distribution peaked toward $y = 0$. LCD would achieve sensitivity comparable to or better than limits derived from terrestrial or astrophysical considerations.[15,16,17] A nonzero charge radius can increase or decrease the cross section and has the effect of flattening the y distribution. LCD limits on such unexpected compositeness fall in the 10^{-33} cm^2 range, better than existing limits by an order of magnitude.

LCD is similar to IMB or KAMIOKANDE II in its ability to detect neutrinos, muons, and electrons from supernovae. Due to its thin overburden, it has significantly higher cosmic-ray-related backgrounds. Nevertheless, electron neutrinos from the prompt collapse phase and delayed high-energy muon neutrinos can be detected.

LCD requires only a small enhancement to its data-acquisition electronics to make this possible. Our estimate for the LCD response to another SN1987A is 35 events, or if this supernova were in our galaxy, 750 events. The range of our estimates for high-multiplicity electrons reaches as high as 16000 events in 10 s.[14] For a modest addition to the hardware, this detector, easily maintainable for a decade because it is on-site at a large national laboratory, offers an attractive capability in neutrino astronomy.

A long history of neutrino experimentation at Los Alamos has set the stage for the next decade of LAMPF research with neutrinos using the Large Čerenkov Detector.

References

1) V. A. Lubimov et al., *Phys. Lett.* **B94**, 266 (1980).
2) S. Boris et al., *JETP Lett.* **45**, 267 (1987); *Phys. Rev. Lett.* **B58**, 2019 (1987).
3) H. Fritschi et al., *Phys. Lett.* **B173**, 485 (1986).
4) J. F. Wilkerson et al., *Phys. Rev. Lett.* **58**, 2023 (1987).
5) E. F. Tretyakov, *Izv. Akad. Nauk. U.S.S.R., ser. fiz.* **39**, 583 (1975).
6) D. A. Knapp, Ph.D. dissertation, Princeton University, 1986, Los Alamos National Laboratory report LA-10877-T; D. L. Wark et al., in "5th Force Neutrino Physics" (Proceedings of the XXIII Rencontre de Moriond, Les Arcs, France: Editions Frontières, Gif-sur-Yvette 1988), ed. by O. Fackler and J. Tran Thanh Van, p. 79.
7) J. F. Wilkerson et al., Proceedings of the XVI INS International Symposium on Neutrino Mass and Related Topics, Tokyo, 16–18 March 1988, ed. by S. Kato and T. Ohshima, World Scientific Publishing Co. Ltd., Singapore, ISBN 9971-50-708-0.
8) R. G. H. Robertson et al., in "Tests of Fundamental Laws in Physics" (Proceedings of VIII Rencontre de Moriond Workshop, Les Arcs, France: Editions FrontiEres, Gif-sur-Yvette 1989), Los Alamos National Laboratory document LA-UR-89-1173.
9) L. S. Durkin et al., *Phys. Rev. Lett.* **61**, 1811 (1988).
10) W. C. Louis, private communication.
11) U. Amaldi et al., *Phys. Rev.* **D36**, 1385 (1987).
12) W. Marciano, Proceedings of Brookhaven National Laboratory Neutrino Workshop, BNL 52079 (1987).
13) C. Lim, Proceedings of Brookhaven National Laboratory Neutrino Workshop, BNL 52079 (1987).
14) A Proposal for a Precision Test of the Standard Model by Neutrino Electron Scattering, Los Alamos Meson Physics Facility, Mail Stop H846, Los Alamos, NM 87545 U.S.A., March 1988.
15) R. C. Allen et al., *Phys. Rev. Lett.* **22**, 2401 (1985).
16) K. Abe et al., *Phys. Rev. Lett.* **58**, 636 (1987).
17) F. Sutherland et al., *Phys. Rev.* **D13**, 2700 (1976).